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Status of Porous Pavement Research

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STATUS OF POROUS PAVEMENT RESEARCH

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Abstract—This paper discusses the U.S. Environmental Protection Agency's porous pavement research program along with the economics, advantages, potential applications, and status and future research needs of porous pavements.

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INTRODUCTION

With the extreme urban growth experienced in the United States over the last 30 years, environmental problems associated with urban land development have grown significantly serious. Specifically, the hydrology of a developing area is severely impacted. The installation of streets, parking lots, rooftops and storm sewers increases total volume of runoff and increases peak stream flows. Downstream flooding often results. Stream stability and water quality are also often effected.

Realizing the effects of urbanization on the hydrological environment, many communities have passed laws encouraging land developers to practice sound stormwater management on their properties. In response, stormwater management methods, which maintain predevelopment or existing runoff levels, are being developed and implemented.

New approaches to stormwater management have focused primarily on detaining and retaining excess runoff on the site. Another alternative approach is to reduce the amount of impervious surfaces added to the site and, therefore, reduce the generation of excess runoff. An available technique for this nongeneration approach is the utilization of porous pavements for parking lots and low traffic volume roadways (Figs 1 and 2).

Applications and research to date have concentrated on the use of asphalt and concrete porous pavement for parking lots. Expanded use of porous pavements for parking lots and secondary roadways will require the collection of more data further defining hydrological characteristics, water quality im-

Fig. 1. Porous pavement (asphalt concrete) site, University of Delaware, Newark, DE.

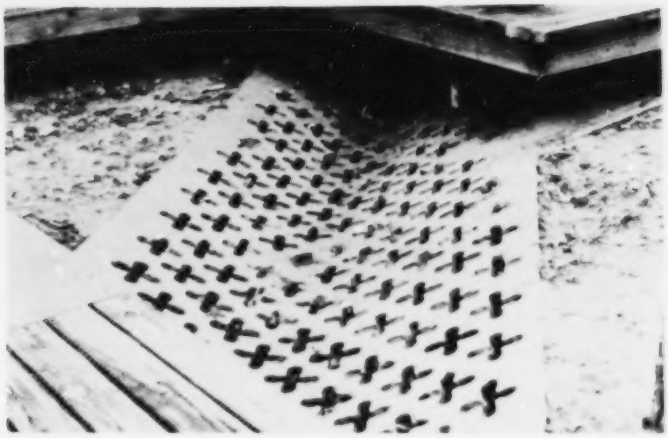

Fig. 5. Porous pavement (grasscrete) site, Woodlands, TX.

at least the past 10 years. Application of this material to airport runways was initiated in 1967 at Farnborough, England (Jones, 1973) by the British Royal Air Force and two European airfields by the United States Air Force. Since 1947, the California Highway Department (Izzard, 1946) has utilized open graded courses under conventional top paving to provide rapid drainage in problem areas.

U.S. ENVIRONMENTAL PROTECTION AGENCY'S POROUS PAVEMENT RESEARCH

The Franklin Institute Research Laboratories (Thelen *et al.*, 1972), under Environmental Protection Agency (EPA) sponsorship, investigated the use of a porous base and a porous subbase in conjunction with a thicker application of the plant mix seal coat. The intent of this experiment was to investigate the potential of delivering water to the subbase rather than removing it to a stormwater collection system. They also evaluated a variety of conventional and unconventional materials. The most promising ones were tested to determine their physical and economic feasibility as porous pavement materials. Of those tested, the open-graded asphalt concrete was selected as the most suitable material because of its superior physical characteristics, its low cost and its ability to be laid by conventional paving methods. Other porous pavement types studied included various types of concrete lattice blocks (Figs 3, 4 and 5).

An economic analysis undertaken during this study determined by pavement type the cost of porous asphalt in relation to conventional pavements with storm sewers, the relative value and market for the identified benefits of porous pavement, and the annual demand for the pavement types considered. Cost estimates for porous asphalt were based on Asphalt Institute specification assuming the minimum base reservoir capacity of 68 cm that would be required in a medium precipitation area like Philadelphia and assuming an average winter frost penetration level. Where the total thickness of surface and base exceeded conventional pavement thickness, an allowance was made for extra excavation costs. In areas of higher or lower precipitation, the cost of porous asphaltic concrete construction would be correspondingly increased or decreased somewhat, because of changes in required base reservoir capacity. Similarly, in areas of heavy frost susceptibility deep gravel bases normally are required to prevent freeze–thaw heaving and the cost of porous construction would be correspondingly more favorable.

The results of the 1972 economic analysis are summarized in Table 1. In most cases, this study found the cost of conventional pavement with storm sewers to be higher than the cost of an equivalent porous asphalt installation without storm sewer relief. However, installations will have to consider the need for some storm sewer relief, until more field data on porous pavements is available. The economics of porous pavements are very site specific as they are governed by design difference, the cost and proximity to the supply of stones and gravel, and the permeability of the adjacent soil. Therefore, each user will be required to do his own economic evaluation when considering the installation of porous pavements.

Initial porous pavement installations in Delaware and Pennsylvania (Engineering News Record, 1973) proved successful on a structural and drainage basis, and subsequent installations in The Woodlands, TX (Diniz & Espey, 1979) and Rochester, NY (Murphy *et al.*, 1981) were scientifically instrumented and monitored to provide greater information on the benefits and/or drawbacks. The Rochester results are discussed later in this text.

Currently, each porous pavement design is unique; therefore, it is evaluated and permitted by regulatory agencies only after a long analysis and review period.

Table 1. Porous pavement benefits 1972 costs (Thelen *et al.*, 1972)

Type of pavement	Annual demand ($1000 m^2$)	Conventional pavement with drainage ($\$ m^{-2}$)	Porous pavement ($\$ m^{-2}$)	Combined sewer relief: Gross demand affected (%)	Combined sewer relief: Added value ($\$ m^{-2}$)	Water supply: Gross demand affected (%)	Water supply: Added value ($\$ m^{-2}$)
Parking lot	38,444	5.66	7.61	18	6.63	24	0.18–0.50
Residential street							
Low-design	111,543	8.61	7.60	18	6.63	24	0.35–0.99
High-design	10,140	12.24	7.63	18	6.63	24	0.38–1.10
Business street							
Suburban development	43,929	10.05	7.63	18	6.63	24	0.35–0.99
City	3993	21.77	9.16	18	6.63	24	0.35–0.99
County road							
Low-volume	161,873	11.05	7.70	18	6.63	24	0.35–0.99
Moderate-volume	170,430				6.63	24	0.39–1.05
Highway							
Two-lane	118,674	17.34	8.80	18	6.63	24	0.39–1.05
Four-lane							
Asphalt	86,963	28.56	10.14	18	6.63	24	0.39–1.05
Concrete		30.90	10.33	18	6.63	24	0.47–1.34
Playground	3676	5.44	7.58				

The EPA, in a cooperative agreement with the City of Austin, Texas (Diniz, 1980), hopes to standardize the design approach, yet allow the designer sufficient latitude for individual creativity. It is expected that the data from this project may be sufficient for standardizing the design of parking areas and residential streets. However, for complex conditions, a thorough analysis by qualified professionals is essential for the design of a porous pavement.

In general, potential as well as existing users and review agencies have expressed a need for data on three conditions regarding porous pavement systems. These conditions are:

1. Construction feasibility, maintenance and design life.
2. Control and management of runoff peak and volumes.
3. Control and management of water quality degradation.

The need to evaluate the runoff changes and water quality constituent changes from urbanizing activity is paramount in the design of porous pavement systems. Unfortunately, most engineering practice holds the view that all pavements have to be evaluated solely from a runoff viewpoint. Only recently has water quality degradation become a point of concern for most practitioners and public officials. It is anticipated that as the concern for water quality of urban runoff becomes recognized, the need for porous pavement parking systems will increase.

POROUS PAVEMENT HYDROLOGICAL DESIGN PHILOSOPHY

To develop the design of a given porous pavement, the design storm, contributing area and soil permeability will determine the storage volume required for the reservoir base (Figs 6 and 7). The selection of the design storm is dependent upon local desires and meteorological phenomenon.

The characteristics of the drainage basin including permeability of the soil, topography and climate will affect the volume and rate of runoff and flow through the porous pavement and existing subsurface soil. Storage capacity, however, can be limited due to physical and economic limitations. If so, relief measures should be incorporated into the system to prevent adverse conditions that could develop such as flooding, freezing, anaerobic or septic conditions.

The considerations discussed herein will result in a design for porous pavements. This design, which was adapted from Thelen & Howe (1978) (Fig. 8) is as follows.

The subbase

All soils under roads may become wet, but they must drain in order to maintain their bearing strength. Because soils under porous pavement will certainly get wet, they must be water permeable; they must not heave due to freezing or thawing, and they must not swell or substantially lose their strength

ments under severe environmental conditions. One of these sites was selected to evaluate the structural integrity and permeability of the porous pavement under conditions of heavy truck traffic (Fig. 9).

Results of the study indicated:

(1) Peak runoff rates were reduced by as much as 83%.

(2) The pavement, which was subjected to 100 freeze/thaw cycles, showed no observable structural degradation. In addition, the water drained through the pavement without problems during the winter.

(3) Through observations and flow monitoring, the structural integrity of the porous pavement installed, where heavy load vehicles were parked, was not impaired.

(4) Clogging did result from runoff carrying a heavy sediment load. Clogging during the test study was relieved through cleaning by flushing.

(5) The cost of constructing a porous pavement parking lot utilizing an impermeable membrane and underdrains ($21 m^{-2}) is slightly higher than that of a conventionally paved lot with stormwater inlets and subsurface piping ($19 m^{-2}). If subsurface soil conditions are adequate to allow passage of the rainfall that infiltrates through the porous pavement, then the impermeable membrane and underdrains are not needed and costs for both types of pavements would be the same.

Austin, TX (Diniz, 1980)

The overall objective of this research is to demonstrate, evaluate and/or determine the feasibility of using various porous pavements. The resulting information will be used to develop design criteria for potential porous pavement construction.

The first phase of this project has been completed and published in an EPA research report entitled, "Phase I—Design and Operational Criteria" (Diniz, 1980). The objective of the work was to accumulate all available design, construction and operational data for existing porous asphalt pavement areas. This report summarizes these data. Phase II of this project, which is still ongoing, is comparing the runoff and water quality characteristics of porous pavements (porous asphalt pavement; concrete lattice blocks) (Figs 10 and 11) to other kinds of conventional (asphalt, concrete, gravel and grass) parking areas.

ADVANTAGES AND DISADVANTAGES OF POROUS ASPHALT PAVEMENT USAGE

Advantages

The primary objective of porous asphalt pavements for this program is to control runoff and associated water quality degradation. Important benefits from porous asphalt pavements include:

(1) Attenuation of the runoff rate and volume. The rate of flow reduction will reduce the need to rehabilitate undersized drainage system segments.

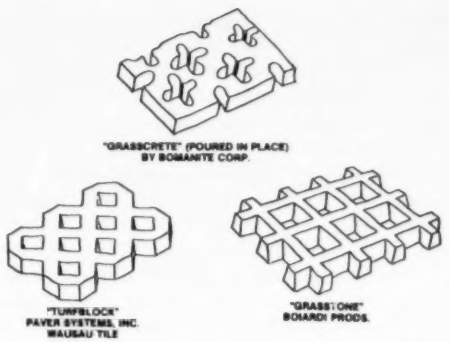

Fig. 10. Concrete porous pavements—"lattice" type pavers.

(2) Improved erosion control.

(3) Enhancement of water quality in areas where the runoff generated from impervious areas has the potential for becoming contaminated. If the pollution is not toxic and depending upon its characteristics, detention in the reservoir layer and percolation through the subbase may be sufficient to reduce the pollution to acceptable levels; however, groundwater pollution may require routing of flow to protect the aquifer. If the stormwater requires treatment for toxic or non-filterable substances, it may be stored in porous pavement systems isolated from the natural ground by an impermeable membrane until treatment plant capacity becomes available. Thus, treatment plant capacity does not need to be expanded and the volume and duration of combined sewer overflows (CSO) are lessened. Also, detention of highly polluted initial runoff by the porous pavement, and dilution by less polluted subsequent runoff can result in acceptable pollutant concentrations throughout the storm duration.

(4) A reduction in the need for curbs and storm sewer installation or expansion.

In areas relatively flat and/or rocky or with minimal soil depths, the cost of installing storm sewers is very high because both sewer size and excavation volumes are increased or excavation is made more difficult. The use of porous pavements in these areas reduces both sewer size and excavation depth, thus resulting in a net saving in drainage costs.

(5) Retention of natural vegetation and drainage patterns.

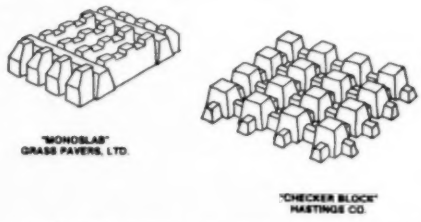

Fig. 11. Concrete porous pavements—"castellated" type pavers.

(6) Reduction or elimination in the nuisance factor to pedestrian and motorist arising from standing puddles and temporary storage in parking lots and streets.

(7) Increase in the amount of groundwater recharge to local aquifers in water deficient areas.

(8) Improved road safety due to a higher friction coefficient, reduction of hydroplaning and thus improved visibility.

Disadvantages

(1) The greatest concern with using porous pavement is its susceptibility to clogging. Based on past experience this problem should not occur if proper care is taken and there is adequate maintenance.

(2) Porous pavement effectiveness has to be evaluated during the melting of ice and snow which has accumulated on its surface or if rain occurs when the subsurface is frozen. The test site in Rochester, NY (Murphy *et al.*, 1981) showed that this was not a problem.

(3) Another disadvantage in the use of porous pavement results from the fact that some existing building codes and regulations are not intended for this new type of technology. Specifically, if conventional drainage structures (curbs, gutters, inlets, etc.) are arbitrarily required in all parking areas, then the construction costs of porous pavement installation became less economically attractive.

(4) A temporary drawback arises out of a lack of data to indicate the capabilities of porous pavement to filter and purify all contaminants in runoff. It could result in more subsurface pollution.

(5) Spillage of gasoline from leaking tanks of automobiles parked on the porous pavement lot will break down the asphalt binder to greater depths than on conventional pavements, primarily because the pores on the open graded mix permit greater gasoline penetration. The solution to this problem may be the use of tar binders rather than asphalt.

Porous pavement is a multi-benefit strategy for pollution and flood control versus other more expensive downstream control strategies. The advantages far outweigh the disadvantages. Consequently, the potential for porous pavement usage is expected to increase as the problems outlined in this section are resolved.

SUMMARY

Porous pavements can be an effective means of reducing the increase in runoff rates and volumes, and water quality degradation, resulting from urbanization and/or other land use changes. The design of porous pavements has to be undertaken with extreme care, particularly in areas where the natural soils do not have sufficient permeability to drain naturally the stored runoff within a reasonable time.

The use of porous pavements is presently limited to parking lots (due to the lack of structural data). Because all runoff from the site as well as adjacent areas draining into the site are effectively retained, the entire area contributing to the porous pavement has been removed from the surface hydrologic regime or retained in the system to permit downstream facilities to treat the stormwater flow. Consequently, the increase in runoff rates and volumes by urbanization is offset by a reduction in impervious areas in an urbanized environment.

The net downstream effect of porous pavements can range anywhere from a reduction of runoff rates and volumes to below pre-installation levels to the elimination of runoff from the immediate area. In either case, the net effect downstream can be of significant benefit; in the case of storm sewers, the sewer requirements may be reduced or eliminated, thereby providing substantial cost reductions; and in the case of combined sewers, the number of overflows will be reduced or eliminated, thereby providing direct benefits to the receiving water. In both cases the cost of additional drainage facilities is reduced; and consequently, the incremental additional cost of porous pavement systems may be recovered.

The water quality of urban runoff has been shown to be severely polluted in some instances, but in all instances the runoff is at least partly contaminated. It is obvious that just the infiltration and velocity reductions in porous pavements will result in some suspended particulate removal and some chemical pollutant reduction. The removal of water from the surface runoff regime prevents the introduction of pollutants into the receiving water and creating problems in downstream areas.

If it is known, or the possibility exists, that water infiltrating into the ground could reach a water supply aquifer, adequate precautions should be taken to determine that the surface runoff is not still contaminated when it reaches the aquifer. If there is a possibility of adversely affecting the aquifer, the porous pavement area should be designed to be sealed off from the aquifer recharge zone or not installed there.

Future requirements of the program

The design of porous pavement parking lots is just emerging from the experimental phase. Most porous pavement users and designers would agree that further research and test demonstration pavement areas must be installed. Although existing porous pavements have performed more than adequately and have required minimal maintenance, some questions still remain. These include quantification of runoff and water quality changes, the long-term effects of continuous saturation of the subgrade, cleansibility, maintenance and potential for clogging, operation in snow, ice and frozen ground conditions, aggregate gradation and asphalt content in the hot mix, construction material types and configurations, regulations and design requirements and the economic efficiency of using this type of pavement under existing regulations.

Instrumented porous pavement systems would be desirable. This instrumentation should provide information on rainfall, drainage, soil moisture and water quality effects; the data provided should be continuous during the progress of a storm and through the soil profile, thereby allowing an evaluation of dynamic changes in runoff and water quality. Toward this end, a detailed analysis is being undertaken by EPA in the Austin, TX (Diniz, 1980) study. This work includes the evaluation of porous pavement and comparison to various other pavement types. The data to be collected should prove helpful in identifying the drainage and water quality benefits to be derived by porous pavements for a variety of rainfall events. Also presently unpredictable problems may be uncovered.

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